DECONSTRUCTING NEUROPSYCHOLOGICAL PRACTICE EFFECTS: CONTRIBUTIONS OF LEARNING AND RESPONSE TO TASK NOVELTY

by

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STATEMENT OF DISSERTATION APPROVAL

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ABSTRACT

Practice effects (PEs) have recently gained popularity in research as a potential indicator of early cognitive decline in older adults. A majority of studies demonstrate decreasing PEs with cognitive decline, presumably due to declining memory; however, some studies have demonstrated larger PEs in the context of cognitive decline. One possible explanation for the inconsistencies in findings is that PEs are the result of multiple cognitive processes that change differentially with cognitive decline. These processes include not only memory, but also the ability to rapidly adapt to novel task demands, termed the novelty effect. We examined PE and its hypothesized components, novelty effect and learning, in 63 older adults with cognitive status ranging from normal to moderately impaired. We investigated the independent contributions of learning and novelty effect to PEs and tested whether two component processes mediated changes in PE across declining cognitive status. Novelty effect and learning each predicted PE on a different test and mediated the relationship between cognitive status and PE on those respective tests. These findings provide support for novelty effect and learning as independent contributors to PE and highlight the need for a better understanding of component processes of PE to improve its utility as a diagnostic indicator.

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INTRODUCTION

Practice effects (PEs) are normal improvements in test performance due to prior exposure to a test (Beglinger, Tangphao-Daniels, et al., 2005; McCaffrey, Duff, & Westervelt, 2000) and are well-known confounds in measuring change in cognitive functioning over time. Practice-related improvements are usually conceptualized as a combination of implicit and explicit learning of task characteristics and have been observed across diverse cognitive domains, age groups, and neurocognitive disorders (Chelune & Franklin, 2003). A majority of literature on PEs frames them as a nuisance variable that masks cognitive decline or overestimates treatment-related cognitive improvement. However, a growing body of literature suggests that PE may have diagnostic utility as a cognitive construct in its own right. For example, a recent meta-analysis of over 1,600 studies of PE found that the magnitudes of PEs not only depend on logistical factors, such as intertest interval or use of alternate forms, but also vary by age and clinical diagnosis (Calamia, Markon, & Tranel, 2012), suggesting that patterns of PE might help to distinguish between diagnostic groups.

Support for the diagnostic and prognostic utility of PEs is evident in numerous studies examining PEs in various clinical populations, with a recent focus on mild cognitive impairment (MCI) and dementia (Duff, 2012; Duff et al., 2007; Duff, Callister, Dennett, & Tometich, 2012; Duff, Chelune, & Dennett, 2012; Machulda et al., 2013). In this line of research, findings have been somewhat mixed. On the one hand, a number of studies have shown that individuals with dementia (Cooper et al., 2001; Duff, Chelune, et al., 2012; Helkala et al., 2002) and MCI (Cooper, Lacritz, Weiner, Rosenberg, & Cullum, 2004; Schrijnemaekers, de Jager, Hogervorst, & Budge, 2006) have smaller PEs than healthy peers. This is an expected finding, given that impairments in learning and memory are common in MCI and dementia (Jonker, Geerlings, & Schmand, 2000; Mitchell, 2008). On the other hand, some studies have shown the opposite result, indicating *greater* PEs in patients with MCI or dementia compared to healthy peers (Duff et al., 2008; Yan & Dick, 2006). Using the current conceptualization of PEs as a reflection of implicit and explicit learning, this result would suggest that patients with MCI show *more* improvement due to learning than do healthy controls. Such paradoxical findings call into question the prevailing conceptualization of PEs as reflecting memory and learning, and suggest that further investigation into the nature of PEs is warranted, especially if PEs are thought of as a cognitive construct that can be utilized for detection of cognitive impairment or risk for cognitive decline.

Several explanations have been offered for the inconsistent findings regarding PEs in MCI. Duff et al. (2008) suggested several factors that could contribute to higher PEs in MCI, including (a) floor or ceiling effects in different patient groups, (b) differential declines in declarative versus procedural learning, and (c) heterogeneity in cognitive status within groups. Alternatively, Suchy, Kraybill, and Franchow (2011) proposed that PEs may be the result of cognitive phenomena beyond learning. In particular, they suggested that greater PEs in MCI patients could be due to a release from novelty effects, which they define as initial transient decrements in performance caused by reaction to novel task characteristics (perhaps due to insufficient cognitive resources to rapidly adapt to novel test demands). Using this model, PEs could be conceptualized as consisting of two components: (a) learning (both implicit and explicit) and (b) rebound from a novelty effect.

Suchy, Kraybill, and Franchow (2011) proposed a theoretical model of PE (Figure 1) to explain paradoxical PE in MCI. The model posits that learning and novelty effect differentially contribute to PE at different points along a trajectory of abnormal (or pathological) cognitive decline that is associated with MCI and/or dementia (Suchy et al., 2011). This model was inspired by the finding that novelty effects (evidenced on a computerized motor programming task) were larger among individuals who exhibited a clinically significant (i.e., pathological) cognitive decline at 1-year follow-up, as compared to novelty effects among cognitively-stable counterparts. Thus, the model hypothesizes that whereas the contribution of learning to PE generally *declines* with pathological declines in cognitive function, the contribution of novelty to PE *increases;* this increase occurs early in the declining trajectory, followed by a decrease as the pathological decline process continues (see Figure 1). These differential contributions of learning and novelty presumably lead to a curvilinear relationship between PE and pathological cognitive decline. Specifically, according to the model, the initial increase in novelty effect is of sufficient magnitude to result in an increase in the net PE early on in the neurodegenerative process (i.e., when memory and learning are still relatively preserved). Once a clinically significant level of cognitive decline is reached (i.e., when memory and learning begin to exhibit notable decrement), PE begins to decline, being now comprised primarily of a novelty effect with little contribution from learning. Finally, as cognitive impairments become more severe, novelty effects also decline (as individuals are no longer able to benefit from becoming familiar with the task characteristics); thus, with minimal to no contributions from learning or novelty effects, PEs also become minimal or even nonexistent.

This model of PE, although interesting, has yet to be tested empirically. In particular, whereas Suchy et al. (2011) demonstrated larger novelty effects among individuals who were at preclinical stages of cognitive decline as compared to non-declining counterparts, the remaining time points on the decline continuum are purely theoretical. In other words, it has not been demonstrated that novelty effects decrease with continued declines in cognition. Further, past research has *not* examined the direct association between novelty effect and PE, or the differential contribution of novelty effect and learning across different points along the cognitive-decline continuum.

The goal of this study was to examine PEs and their proposed components (i.e., learning and novelty effects) in older adults across a spectrum of cognitive functioning through three primary aims. First, we sought to identify whether novelty effects and learning independently contribute to PE. We hypothesized that both learning and novelty effect would emerge as independent predictors of PE. Second, we investigated whether the relationship between PE and cognitive impairment in older adults is linear (as would be expected if PEs were largely a function of learning) or quadratic (as predicted by the Suchy model of PE). We hypothesized that PEs would be greater in the context of mild cognitive dysfunction relative to intact or moderately impaired cognitive functioning. Third, we examined whether learning and/or novelty effects mediate the relationship between PE and cognitive functioning. Our model of PE predicts that an increase in PE with mild cognitive dysfunction is due to a larger novelty effect in spite of a reduced capacity for learning; thus it was hypothesized that novelty effects and learning would mediate the relationship between PE and cognitive functioning.

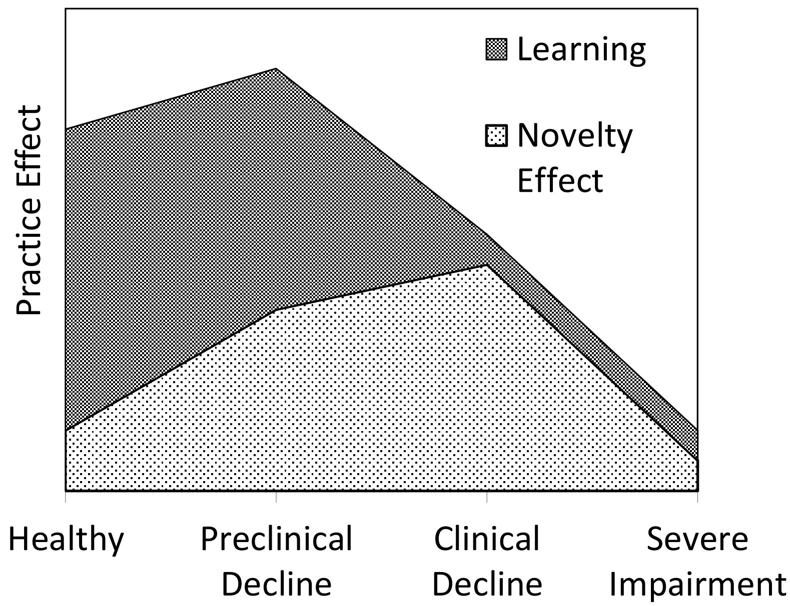

Figure 1

Theoretical model of components of practice effect across a spectrum of cognitive decline. Reprinted with permission of Cambridge University Press from Suchy, Y., Kraybill, M. L., & Franchow, E. (2011). Practice effect and beyond: Reaction to novelty as an independent predictor of cognitive decline among older adults. *Journal of the International Neuropsychological Society, 17*(1), 101-111.

METHOD

Participants and Recruitment

Participants included 75 adults (43.1% male) ages 60 to 89 with and without cognitive impairment. Years of education in the sample ranged from 11 to 20 years (M = 15.38, SD = 2.80). Participants were recruited from the University of Utah's Center for Alzheimer's Care, Imaging, and Research as well as from the community (i.e., senior centers, assisted living facilities, and health fairs). Because our model hypothesizes that contributions of learning and novelty effect to PE change across the *early stages* of pathological cognitive decline, individuals who exhibited moderate to severe impairment on cognitive screening were excluded. Additional exclusion criteria were left-handedness, age less than 60 or greater the 89, severe symptoms of depression, history of serious neurological disorder (e.g., stroke, seizures, multiple sclerosis, moderate to severe brain injury), and serious psychiatric illness (e.g., psychosis, treatment resistant depression). Of the initial sample of 75, 2 participants were excluded for severe depressive symptoms, 7 were excluded due to incomplete data, and 3 were excluded due to extreme values on measures of PE or novelty effect, reflective of invalid performance.

Procedures

The study was approved by the University of Utah Institutional Review Board. Participants were screened for exclusion criteria by telephone using a brief medical history interview and a cognitive screening measure. Written informed consent was obtained from participants (and a legally authorized representative, if applicable) prior to their participation in the study. Participants completed a 2-hour battery of tasks assessing general cognitive status, word list learning and memory, and motor sequencing. After completing the study, participants were fully debriefed and compensated $10 per hour of participation.

Measures

Eligibility screening. To prescreen for inclusion/exclusion criteria, participants completed a brief telephone interview to provide demographic information and medical history. The *Telephone Interview of Cognitive Status* (TICS; Brandt, Spencer, & Folstein, 1988) was used to screen for cognitive status prior to study enrollment. The TICS has demonstrated a high correlation (r = .94) with the MMSE and excellent sensitivity (94%) and specificity (100%) for distinguishing demented from nondemented participants (Brandt et al., 1988). Scores range from 0 to 41. Following the Brandt et al. (1988) recommended interpretive ranges for cognitive status, a cut-off score of 21 or above was selected to obtain a sample with cognitive status ranging from mildly impaired to nonimpaired.

Participants were screened for depression using the Geriatric Depression Scale (GDS; Yesavage, 1982), a brief, self-report measure designed to assess depressive symptoms relevant to an aging population. It has good validity and reliability among community-dwelling older adults (Dunn & Sacco, 1989; Yesavage, 1982) as well as in adults with mild to moderate dementia (Feher, Larrabee, & Crook, 1992). Participants with scores above 19 (indicating severe depressive symptoms) were excluded from analyses.

Cognitive decline. Abnormal cognitive decline was operationalized as a deviation from expected performance on the *Mattis Dementia Rating Scale,* 2nd edition (DRS-2; Mattis, 1988). The DRS-2 is a brief screening measure used in the assessment of general cognitive status and includes domains of attention, initiation, abstraction, visual-constructional abilities, as well as verbal and nonverbal memory. The DRS-2 total raw scores have good reliability and validity (Strauss, Sherman, & Spreen, 2006).

It is important to note that DRS-2 raw scores are affected by demographic factors such as age and educational attainment. Therefore, low raw scores do not necessarily reflect abnormal cognitive decline; rather, they may reflect poorer performance due to advanced age or low educational attainment. In contrast, age and education adjusted scaled scores reflect a deviation (i.e., a *decline* in cases of a negative deviation) from a normatively expected premorbid ability. For these reasons, age and education adjusted scaled scores were used in all analyses. As explained in the test manual, DRS-2 raw scores had been standardized such that scaled scores of 11 and above represent "average" (i.e., normatively expected) or higher cognitive functioning whereas scaled scores of 10 and below represent progressively greater deviation from normative expectations (Mattis, 1988).

Practice effects. Following recent methods in PE research (Darby, Maruff, Collie, & McStephen, 2002; Duff, Chelune, et al., 2012), within-session PEs were measured using repeated administration of the Symbol Search and Coding subtests of the *Wechsler Adult Intelligence Scale,* 4th edition (WAIS-IV; Wechsler, 2008). These tests were selected because (a) they were not designed to assess memory or novelty effect (Wechsler, 2008), and therefore would not be expected to confound contributions of memory and novelty effect to PE; (b) they are known to exhibit sizeable practice effects as compared to, for example, measures of crystallized intelligence (Estevis, Basso, & Combs, 2012); and (c) they were presumed to assess the same construct regardless of repeated administrations, which is not the case for all measures (e.g., for tests of reasoning and problem solving the first administration taps one's ability to devise a solution or a strategy, but the second administration taps only the ability to apply that same previously devised strategy or solution).

First and second administrations of the Symbol Search and Coding subtests were separated by a 30-minute interval. PEs for each subtest were calculated as the change in raw scores between the first and second administrations. Raw scores were used to provide a broader range of values in order to improve sensitivity to practice-related changes. Means and standard deviations for both scaled and raw scores for the first administration of the Symbol Search and Coding subtests are included in Table 1. Note that the two subtests were originally included in the study with the intent to create a single PE composite score to optimize reliability. However, as seen in Table 2, the two PE variables did not correlate with each other; therefore, they were examined separately in all analyses.

Learning. The *Rey Auditory Verbal Learning Test* (RAVLT; Schmidt, 1996) is a 15-item list learning and memory task that includes 5 learning trials and a delayed (20 to 30 minutes) recall trial. Research suggests that the RAVLT has good test-retest reliability and validity (Schmidt, 1996). Learning was operationalized as total recall across 5 learning trials as this variable was normally distributed and had a greater range of scores than delayed recall scores.

Novelty effect. Novelty effects were measured using the *Push-Turn-Taptap* (PTT) task (Suchy & Kraybill, 2007), an electronically administered motor programming task from the Behavioral Dyscontrol Scale, Electronic Version (BDS-EV; Suchy, Derbidge, & Cope, 2005) in which participants perform sequences of three unique hand movements across four blocks using a specialized response console (see Figure 2). The hand movements include (a) "Push," pushing a joystick away from them; (b) "Turn," turning a joystick clockwise; and (c) "Tap-tap," double-tapping on a large dome-shaped button. The four task blocks progressively increase in difficulty from a sequence combination of two movements to five movements. The PTT task yields several indices of motor performance, including motor speed, motor planning time, motor learning (accuracy), perseverative errors, and latency between taps. From among these, the present study focuses on motor planning latencies, as these have been shown to exhibit novelty effects in prior studies (Suchy, Euler, & Eastvold, in press; Suchy & Kraybill, 2007; Suchy et al., 2011). Motor planning latencies represent the time elapsed between completion of one sequence and the initiation of the next correct sequence. Following procedures from prior studies (Suchy et al., in press; Suchy et al., 2011), novelty effects were calculated as the difference in motor planning latency between the second to the first blocks of the PTT task. For additional details about the PTT task, see Suchy et al. (2011).

Table 1

Descriptive statistics for sample

	Mean	Std. Dev.	Min	Max
Age (years)	74.49	6.72	60	89
Education (years)	15.38	2.80	11	20
GDS	5.37	5.00	0	18
DRS-2	8.86	3.27	2	14
PE_{Coding}	6.13	5.26	-7	18
PE_{Search}	3.65	3.90	-8	11
Learning	39.98	13.70	16	67
Novelty effect (ms)	98.21	208.52	-492.50	614.50
Coding raw score Time 1	47.90	12.25	14	75
Coding scaled score Time 1	9.91	2.69	1	16
Symbol Search raw score Time 1	23.19	6.67	7	34
Symbol Search scaled score Time 1	10.29	2.84	3	16

Note. GDS=Geriatric Depression Scale. DRS-2=Age and education adjusted scaled scores for the Mattis Dementia Rating Scale, 2nd edition. PE_{Coding}=practice effect calculated as difference between time 2 and time 1 raw scores on WAIS-IV Coding. PE_{Search}=practice effect calculated as difference between time 2 and time 1 raw scores on WAIS-IV Symbol Search. Learning=Rey Auditory Verbal Learning Test Total Immediate recall. Novelty effect=difference in motor planning times between first and second blocks of a motor learning task.

Table 2

Bivariate Pearson product correlations among dependent and independent variables

	Age	Educ.	GDS	Learn	Novelty Effect	PE_{Coding}	PE_{Search}
Education	.044	-					
GDS†	.159	-.321*	-				
Learning	-.456**	.192	-.150	-			
Novelty effect†	-.175	.093	-.022	.155	-		
PE_{Coding}	-.309*	.012	-.154	.377**	.041	-	
PE_{Search}	.055	.179	.116	.040	.386**	.057	-
DRS-2	-.102	.135	.085	.689**	.010	.311*	.036

*$p < .05$. **$p < .01$. †Lower values reflect better performances.
Note. DRS-2=Age and education adjusted scaled scores for the *Mattis Dementia Rating Scale*, 2nd edition. Learning=*Rey Auditory Verbal Learning Test* Total Immediate recall. Novelty effect=difference in motor planning times between the first and second blocks of a motor learning task. PE_{Coding}=practice effect for WAIS-IV Coding. PE_{Search}=practice effect of WAIS-IV Symbol Search. GDS=Geriatric Depression Scale.

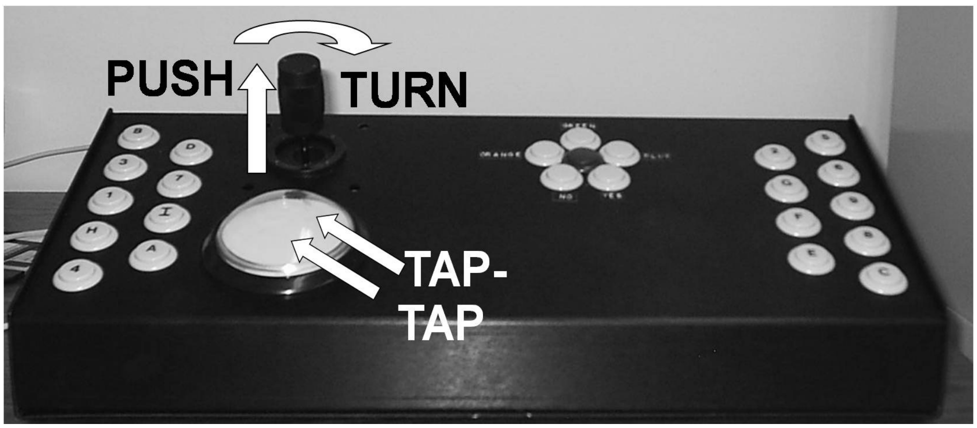

Figure 2

Response console for the Push-Turn-Taptap (PTT) task

RESULTS

Preliminary Analyses

Descriptive statistics for the final sample (n=63) are displayed in Table 1. Pearson product correlations between independent and dependent variables, as well as demographics and depression symptoms, are displayed in Table 2. Practice effects on WAIS-IV Symbol Search (PE_{Search}) were positively correlated with novelty effects (p = .002), but no other variables. In contrast, practice effects on WAIS-IV Coding (PE_{Coding}) were positively correlated with learning (p = .002) and cognitive functioning (p = .013), which were also positively correlated with each other (p < .001). In addition, age was negatively correlated with PE_{Coding} (p = .014) and, as would be expected, learning (p < .001). As mentioned earlier, PE_{Coding} and PE_{Search} were not correlated and thus were examined separately in primary analyses.

Contributions of Learning and Novelty Effect to Practice Effect

To examine independent contributions of novelty effects and learning to PE, hierarchical regressions were used with PE_{Search} and PE_{Coding} as the criterion variables. Learning and novelty effects were used as predictors at Steps 1 and 2, respectively, and subsequently reversed (i.e., Steps 2 and 1, respectively) to examine the unique contributions of learning and novelty effects above and beyond each other. As seen in Table 3, the model of PE_{Coding} was significant only when learning was included, and learning alone predicted PE_{Coding} (b = .146, *beta* = .380, $t(62) = 3.14$, p = .003) with greater learning associated with larger PE_{Coding}.[1] In contrast, the model of PE_{Search} was significant only when novelty effects were included, and novelty effects emerged as the sole independent predictor of PE_{Search} (b = .07, *beta* = .389, $t(62) = 3.228$, p = .002) with larger novelty effects associated with larger PE_{Search}. In sum, consistent with our hypotheses, these results show that learning and novelty effects have unique effects on PE, although each contributed to PE on a different measure.

As a supplement to the principal analyses outlined above, we also considered the potential role of covariates. In the present sample, correlations emerged among age, cognitive decline, and learning. However, in clinical neuropsychology, both age and education are typically taken into consideration as covariates of cognitive performance. For that reason, we repeated the above analyses, including both age and education as covariates. These analyses yielded the same pattern of results as our principal analyses (all ps < .05), demonstrating that the present findings cannot be explained by demographic factors.

Relationship Between Cognitive Decline Status and Practice Effect

To test the Suchy (2011) model of PE, we next examined whether the relationship between abnormal cognitive decline and PE was best represented by linear or quadratic functions. To that end, we ran additional regression analyses, again using PE_{Search} and

[1] Analyses using delayed recall yielded a pattern of results similar to those found using total learning over trials. Specifically, consistent with results using total learning, delayed recall was a significant predictor of PE_{Coding} (p = .049) but not PE_{Search} (p = .935).

PE_{Coding} as the criterion variables. In these analyses, the DRS-2 scaled scores[2] and a quadratic term for DRS-2 scaled scores were used as predictors. As recommended by Cohen, Cohen, West, and Aiken (2003), DRS-2 scores were centered prior to calculating the quadratic term to reduce colinearity between the linear and quadratic terms. Results indicated a positive linear effect of cognitive status on PE_{Coding} (linear term: $b = .682$, $beta = .424$, $t(62) = 3.143$, $p = .003$). In contrast, cognitive status showed a quadratic relationship with PE_{Search} (quadratic term: $b = -.124$, $beta = -.377$, $t(62) = -2.743$, $p = .008$), such that larger PE_{Search} was associated with intermediate cognitive decline (i.e., low average cognitive status, approximate DRS-2 scaled score = 8), whereas smaller PE_{Search} was associated both with no decline (i.e., highest cognitive status) and with the greatest decline (i.e., the lowest cognitive status). When the above analyses were repeated including age and education as covariates, results followed a similar pattern with cognitive status demonstrating a linear effect on PE_{Coding} and a quadratic effect on PE_{Search} (all ps $\leq .01$), indicating that these results were not explained by demographic factors.

Together these results offer partial support for the Suchy (2011) model of PE. Specifically, consistent with Suchy's (2011) model, PE_{Search} was a quadratic function of cognitive status. However, rather than occurring at a preclinical level of decline, PE_{Search} reached a peak at an approximate DRS-2 scaled score of 8, which is on the cusp of clinical impairment per DRS-2 normative standards (Mattis, 1988). In contrast, the relationship between cognitive status and PE_{Coding} is consistent with traditional expectations of declining PE with cognitive decline.

[2] As a reminder, we used DRS-2 scaled scores (as opposed to raw scores) as an indicator of cognitive decline as they represent performance relative to expectations based on age and education.

Mediation Analyses

To determine whether the relationships between PE and cognitive status were mediated by learning or novelty effect, we conducted simple mediation analyses. Simple mediation analysis partitions the *total effect* of an independent variable *X* on a dependent variable *Y* into two separate components: the direct effect and the indirect effect. The *direct effect* of *X* represents the effect of *X* on *Y* that is independent of the proposed mediator, *M*. The *indirect effect* is the effect of *X* on *Y* that is accounted for by *M*. These effects are estimated using the following set of regression equations:

$$(1)\quad Y = i_1 + cX$$

$$(2)\quad M = i_2 + aX$$

$$(3)\quad Y = i_3 + bM + c'X$$

where *c* is an estimate of the *total effect* of *X* on *Y*, *a* is an estimate of the *direct effect* of *X* on *M*, *b* is the *direct effect* of *M* on *Y* independent of *X*, and *c'* is an estimate of the *direct effect* of *X* on *Y* independent of *M*. The *indirect effect* of *X* on *Y* through *M* is quantified as the product of *a* and *b*, which represents the rate at which *Y* changes as a function of both *X* and *X*'s effect on *M*. Thus the *total effect* of *X* on *Y* is the sum of the *indirect* and *direct effects*: $c = ab + c'$. For a detailed explanation of these concepts, see Hayes and Preacher (2010).

Because learning and novelty effects were differentially related to the two PE variables (i.e., Coding and Search), each PE variable was examined in a separate set of mediation analyses. For both sets of analyses, PE variables served as the dependent variables (*Y*), cognitive decline as the proposed causal variable (*X*), and learning or novelty effect as mediators (*M*). Following from the results of our first aim (i.e., contributions of learning and novelty effect to PE), we examined learning as a mediator of the effect of cognitive status on PE_{Coding} and novelty effect as a mediator of the effect of cognitive status on PE_{Search}. Table 4 shows the models used in the mediation analyses for PE_{Coding} (panel A) and PE_{Search} (panel B). These are also depicted as path models in Figure 3.

Tests of direct effects. R^2 and *p* values for models estimated in the mediation analyses are displayed in Table 4. As shown in Table 5, both PE_{Coding} (Model 1) and learning (Model 2) decrease with greater abnormal cognitive decline. Table 5, Model 3 shows the direct effect of learning on PE_{Coding} as a trend, not quite reaching significance. When covariates were included in the models, results showed a similar pattern, although the direct effect of learning on PE_{Coding} was smaller and was not significant (p = .434).

With respect to mediation analysis for PE_{Search}, both PE_{Search} (Table 6, Model 4) and novelty effect (Table 6, Model 5) showed quadratic direct effects of abnormal cognitive decline, such that they both increased as cognitive status ranged from impaired to low average (approximate inflection point at DRS-2 scaled score = 8) and decreased as cognitive status increased beyond low average. In addition, as seen in Table 6, Model 6, novelty effects had a positive direct effect on PE_{Search}. Results followed a similar pattern when covariates were included in the models.

Together these results are generally consistent with the Suchy (2011) theoretical model. Specifically, as theorized by the model, with progressive overall cognitive decline there is a progressively greater decline in memory. In contrast, there appears to be a brief *increase* in the novelty effect early on in the declining trajectory, followed by a subsequent decrease. This decrease occurred earlier in the decline trajectory than was hypothesized in Suchy's (2011) theoretical model. Specifically, the novelty effect was hypothesized to increase until a clinically significant level of cognitive decline (i.e., mild impairment) was reached, followed by a decrease as impairment became more severe.

Tests of indirect effects. The MEDCURVE procedure for SPSS (Hayes & Preacher, 2010) was used to estimate indirect effects of the mediation models for PE_{Coding} and PE_{Search} because it is applicable to nonlinear models and thus could be used to test the hypothesized quadratic indirect effect of cognitive status on PE_{Search} and novelty effects. The MEDCURVE procedure provides a test of significance for the indirect effect by generating bias-corrected bootstrap confidence intervals (CIs) for the indirect effect. The bootstrapping procedure uses sampling with replacement to generate a large number of samples (with *n* equal to that of the original sample size) from the original data and computes CIs for the indirect effect. CIs that *do not* include zero indicate significant results. The bootstrapping method provides a more accurate test of significance of the indirect effect because it does not assume that the variables are normally distributed and it can be applied to small samples (Preacher & Hayes, 2004). Additionally, this procedure minimizes the probability of spurious findings that could be related to idiosyncratic characteristics of a given sample. In contrast to linear mediation models where the indirect effect is constant for all values of *X*, in nonlinear models the indirect effect changes across values of *X*. For nonlinear models, the rate at which a change in *X* changes *Y* indirectly through changes in *M* is called an *instantaneous indirect effect* and is denoted by Θ_x. To test for significance of the instantaneous indirect effect in nonlinear models, the MEDCURVE procedure enables computation of Θ_x and associated CIs for specified values of *X*. As recommended by Preacher and Hayes (2010), we used 5,000 bootstrap samples in MEDCURVE to create 95% confidence intervals for the indirect effect of cognitive status on PE_{Coding} and instantaneous indirect effects of cognitive status on PE_{Search}.

With respect to PE_{Coding}, the indirect effect of cognitive status on PE_{Coding} through learning was significant (*indirect effect* = .343; 95% CI = .057 to .698), but the mediation effect of learning cannot be interpreted because the effect of learning did not quite reach significance (see Table 5, Model 6); this was likely due to a high correlation between cognitive status and learning, which led to overlapping variance between cognitive status (semipartial r = .071) and learning (semipartial r = .224) in prediction of PE_{Coding}. In other words, this result means that learning trended toward mediating the relationship between cognitive status and $PE_{Coding.}$[3] When covariates (i.e., age and education) were included in the model, this trend was eliminated (*indirect effect* = .158; 95% CI = -.246 to .602) and the effect of learning was not significant (p = .434). Once again, this result is likely due in part to shared variance among age (semipartial r = -.181), cognitive status (semipartial r = .127), and learning (semipartial r = .094) associated with high correlations among these variables. Together, these results show that learning may be a potential mediator of changes in PE with cognitive decline, but appears to measure effects on PE_{Coding} that are similar to those explained by DRS-2 scaled scores and age.

[3] Results using RAVLT delayed recall indicated that delayed recall did not contribute to prediction of PE_{Coding} above and beyond cognitive status (b = .269, *beta* = .253, t = 2.009, p = .585) nor mediate the relationship between cognitive status and PE_{Coding} (c' = .093; CI = -.244 to .429). These latter findings may have been partly due to the high correlation between DRS-2 scaled scores and delayed recall (r = .652, p < .001), which resulted in minimal unique variance in PE_{Coding} explained by delayed recall (semipartial r = .067).

Next we examined PE_{Search} and novelty effects. Once again, coefficients and R^2 are displayed in Table 4 and an illustration of the model is shown in Figure 3B. Consistent with our hypothesis, novelty effects mediated the relationship between PE_{Search} and cognitive status for the equivalent of DRS-2 scaled scores of 6 and below (*instantaneous indirect effect,* $\Theta_{DRS=6}$ = .142; 95% CI = .021 to .399) and a significant negative instantaneous indirect effect of cognitive status on PE_{Search} for the equivalent of DRS-2 scaled scores of 13 and above (*instantaneous indirect effect,* $\Theta_{DRS=13}$ = -.337; 95% CI = -1.028 to -.005). When covariates (i.e., age and education) were included in the model, the general pattern of results remained largely unchanged, with novelty effects mediating the effect of cognitive status on PE_{Search} at DRS-2 scores of 6 and below (impaired status; *instantaneous indirect effect,* $\Theta_{DRS=6}$ = .130 ; 95% CI = .006 to .413) and at DRS-2 scores of 14 (above average cognitive status; *instantaneous indirect effect,* $\Theta_{DRS=14}$ = -1.215; 95% CI = -.417 to -.007). These results indicate that novelty effects accounted for the effects of cognitive status on PE_{Search} at impaired levels of cognitive status and above average cognitive status, and that these relationships are not due to demographic factors. However, novelty effect did not explain the effects of cognitive status on PE_{Search} for average to low average status. Taken together, the mediation analyses suggest that changes in PE with cognitive decline may be attributable to specific cognitive processes associated with measures used to calculate PE.

Table 3

Novelty effect and learning as predictors of PE on WAIS-IV Coding and Symbol Search tests

Outcome Variable	Model	Independent Variables in Model	$R^2\Delta$	$F\Delta$	df1	df2	*p*
PE_{Coding}	1_a	Learning	.142	10.117	1	61	.002
	2_a	Novelty effect	.000	.021	1	60	.885
	1_b	Novelty effect	.002	.104	1	61	.748
	2_b	Learning	.141	9.857	1	60	.003
PE_{Search}	1_a	Learning	.002	.096	1	61	.757
	2_a	Novelty effect	.148	10.421	1	60	.002
	1_b	Novelty effect	.149	10.673	1	61	.002
	2_b	Learning	.000	.029	1	60	.865

Note. PE_{Coding}=practice effect for WAIS-IV Coding. PE_{Search}=practice effect of WAIS-IV Symbol Search. Learning=Rey Auditory Verbal Learning Test total immediate recall. Novelty effect=difference in motor planning times between the first and second blocks of a motor learning task.

Table 4

Regression results for models used in mediation analyses of cognitive status on (A) WAIS-IV Coding practice effect through learning and (B) WAIS-IV Symbol Search through novelty effect

	Model	R^2	F	df1,df2	p
A	(1) $PE_{Coding} = i_1 + c(\text{DRS-2})$	.097	6.555	1,61	.013
	(2) $\text{Learning} = i_2 + a(\text{DRS-2})$	.475	55.114	1,61	<.001
	(3) $PE_{Coding} = i_3 + c'(\text{DRS-2}) + b(\text{Learning})$	.147	5.184	2,60	.008
B	(4) $PE_{Search} = i_4 + c_1(\text{DRS-2}) + c_2(\text{DRS-2})^2$	.113	3.806	2,60	.028
	(5) $\text{Novelty} = i_5 + a_1(\text{DRS-2}) + a_2(\text{DRS-2})^2$	.085	2.784	2,60	.070
	(6) $PE_{Search} = i_6 + c'_1(\text{DRS-2}) + c'_2(\text{DRS-2})^2 + b(\text{Novelty})$	.203	5.024	3,59	.004

Note. df=degrees of freedom. PE_{Coding}=practice effect for WAIS-IV Coding. PE_{Search}=practice effect of WAIS-IV Symbol Search. Learning=Rey Auditory Verbal Learning Test total immediate recall. Novelty=difference in motor planning times between first and second blocks of a motor learning task. i=intercept. c=total effect of DRS-2 on PE. a=direct effect of DRS-2 on mediator. b=direct effect of mediator on PE independent of DRS-2. c'= direct effect of DRS-2 on PE independent of mediator.

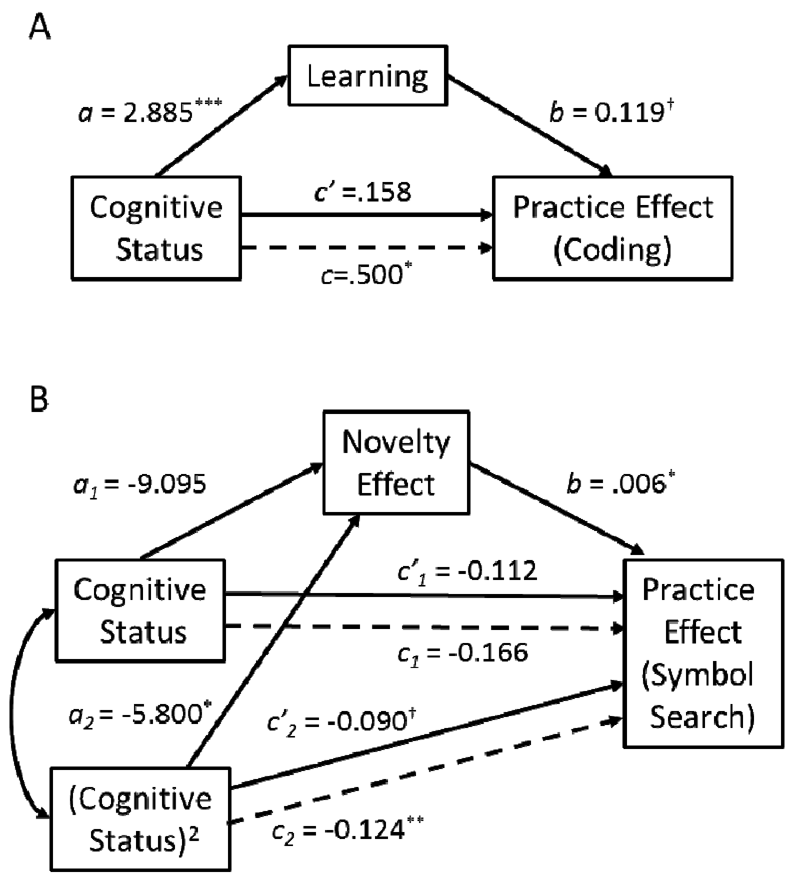

Figure 2. Coefficients for mediation models for practice effect on WAIS-IV Coding (A) and Symbol Search (B) tests.

Note: $n = 63$. Dotted lines indicate the effect of cognitive status on PE when the mediator is excluded from the model. *a*, *b*, *c*, and *c'* are unstandardized regression coefficients.

$^{\dagger} p < .10$, $^{*} p < .05$, $^{**} p < .01$, $^{***} p < .001$

Table 5

Mediation analysis for cognitive status on WAIS-IV Coding practice effect through learning (standard errors in parentheses)

		Model 1			Model 2			Model 3	
Outcome Var. →		PE_{Coding}			Learning			PE_{Coding}	
Predictor		B	*p*		B	*p*		B	*p*
Intercept		1.695	.362		14.431	<.001		-0.019	.993
		(1.844)			(3.667)			(2.023)	
DRS-2	*c*→	0.500	.013	*a*→	2.885	<.001	*c′*→	0.158	.552
		(0.195)			(0.389)			(0.264)	
Learning							*b*→	0.119	.065
								(0.063)	

Note. All coefficients are unstandardized ordinary least squares regression coefficients. PE_{Coding}=practice effect on WAIS-IV Coding. DRS-2=age and education adjusted scaled scores for the *Mattis Dementia Rating Scale*, 2nd edition. Learning=*Rey Auditory Verbal Learning Test* total immediate recall. *c*=total effect of DRS-2 on PE_{Coding}. *a*=direct effect of DRS-2 on learning. *b*=direct effect of learning on PE_{Coding} independent of DRS-2. *c'*= direct effect of DRS-2 on PE_{Coding} independent of learning.
Model 1: PE_{Coding} = intercept + *c*(DRS-2) + error
Model 2: Learning = intercept + *a*(DRS-2) + error
Model 3: PE_{Coding} = constant + *c'*(DRS-2) + *b*(Learning) + error

Table 6

Mediation analysis for cognitive status on WAIS-IV Symbol Search practice effect through novelty effect (standard errors in parentheses)

		Model 4			Model 5			Model 6	
Outcome Var. →		PE_{Search}			Novelty			PE_{Search}	
Predictor		B	*p*		B	*p*		B	*p*
Intercept		4.961	<.001		159.310	<.001		4.021	<.001
		(0.671)			(36.389)			(0.736)	
DRS-2	c_1 →	-0.166	.316	a_1 →	-9.095	.310	c_1' →	-0.112	.481
		(0.164)			(8.892)			(0.158)	
$(\text{DRS-2})^2$	c_2 →	-0.124	.008	a_2 →	-5.800	.022	c_2' →	-0.090	.051
		(0.045)			(2.460)			(0.045)	
Novelty							b→	0.006	.012
								(0.002)	

Note. All coefficients are unstandardized ordinary least squares regression coefficients. PE_{Search}=practice effect on WAIS-IV Symbol Search. DRS-2=age and education adjusted scaled scores for the Mattis Dementia Rating Scale, 2nd edition. Novelty=novelty effect calculated as the difference in motor planning times between first and second blocks of a motor learning task. *c*=total effect of DRS-2 on PE_{Search}. *a*=direct effect of DRS-2 on learning. *b*=direct effect of novelty on PE_{Search} independent of DRS-2. *c'*= direct effect of DRS-2 on PE_{Search} independent of novelty.

Model 4: PE_{Search} = constant + c_1(DRS-2) + c_2(DRS-2)^2 + error

Model 5: Novelty effect = constant + a_1(DRS-2) + a_2(DRS-2)^2 + error

Model 6: PE_{Search} = constant + c'_1(DRS-2) + c'_2(DRS-2)^2 + b(NE) + error

DISCUSSION

The present study examined a theoretical model (proposed by Suchy et al., 2011) of the interrelationships among cognitive status, learning, novelty effects, and practice effects (PEs) in a sample of older adults across a spectrum of abnormal cognitive decline. The key findings of this study were that (a) the PE is not a unitary construct; (b) the relationship between PE and cognitive status is linear for some, and curvilinear for other, measures of PE; and (c) the relationship between cognitive status and PE on WAIS-IV Symbol Search is explained by novelty effects, particularly at impaired and above average levels of cognitive functioning.

Some aspects of these results were consistent with the original hypotheses and partially support the hypothesized model of PE, but others were unexpected. With respect to the expected findings, our results support the hypothesized contribution of both learning and novelty effects to PEs. Additionally, our results are consistent with the notion that novelty and cognitive decline have a nonlinear relationship with each other, and that novelty effect mediates nonlinear changes in PEs as a function of cognitive decline. However, contrary to expectation, our two measures of PEs were *not* correlated with each other, and therefore needed to be analyzed separately. These separate analyses revealed that the two PEs were differentially related to learning and novelty effects, such that learning predicted PEs on WAIS-IV Coding (PE_{Coding}) whereas novelty effects predicted PEs on WAIS-IV Symbol Search (PE_{Search}).

Although the finding that the two PEs are not correlated is consistent with previous research showing that the magnitudes of PEs may vary substantially across different cognitive domains (Basso, Carona, Lowery, & Axelrod, 2002; Duff et al., 2010; Duff et al., 2008), our results are nevertheless somewhat unexpected given that both Coding and Symbol Search are intended to assess the *same* cognitive domain. One interpretation of this finding is that each of these processing speed measures draws upon different component processes beyond speed, and these component processes are then differentially facilitated by practice. Indeed, memory appears to facilitate performance on WAIS-IV Coding above and beyond speed (Joy, Fein, & Kaplan, 2003; Joy, Fein, Kaplan, & Freedman, 2000; Joy, Kaplan, & Fein, 2004); thus memory for number-symbol pairs likely contributed to the magnitude of PE_{Coding}. In contrast, memory processes would offer little support on Symbol Search retest, which may rely more on executive and visual processing (Sweet et al., 2005).

If unique cognitive processes contribute to PEs on different measures, one might expect variability in patterns of PEs across a spectrum of cognitive decline. Indeed, in examining the respective relationships between cognitive status and PE_{Coding} or PE_{Search}, we found the hypothesized quadratic relationship between PE_{Search} and cognitive status, but a linear relationship between PE_{Coding} and cognitive status. This finding parallels mixed results in the literature regarding changes in PE with cognitive decline (Cooper et al., 2004; Duff et al., 2008; Duff, Chelune, et al., 2012; Yan & Dick, 2006), and suggests that differences in PE between impaired and nonimpaired groups are likely to depend on the specific measure used for assessment of practice and the cognitive processes on which it draws. For example, cognitive impairment is likely to be associated with smaller PE on tests of memory (Schrijnemaekers et al., 2006; but see Duff et al., 2008 for contradictory results), whereas it may lead to larger PE on other measures, such as motor control tasks (e.g., Yan & Dick, 2006).

This notion is further supported by the results of our mediation analyses wherein novelty effects and learning emerged as potential mediators of the relationship between cognitive decline and PEs. Specifically, learning demonstrated a trend toward mediating the effect of cognitive decline on PE_{Coding} and novelty effects mediated the effect of cognitive decline on PE_{Search}. Notably, novelty accounted for the effect of above average cognitive status on PE_{Search} and also accounted for decreasing PE_{Search} as cognitive status ranged from mildly to moderately impaired. As seen in Figure 1, this inflection point is generally consistent with the inflection point hypothesized by the Suchy et al. (2011) model. The fact that the increase in PE_{Search} is contained within a relatively narrow window of cognitive decline suggests the possibility that novelty effects may be useful in identifying preclinical pathological decline. Indeed, previous work by these authors has demonstrated the utility of novelty effects in predicting cognitive decline in older adults above and beyond learning (Suchy et al., 2011).

Taken together, the results of the present study suggest that PE is a nonunitary construct that demonstrates variable patterns of change across a spectrum of cognitive status; these patterns, in turn, may depend on the unique cognitive processes involved in repeat performance on any given measure. In addition, these findings provide support for novelty effect as a unique contributor to PEs that may have utility for detection of preclinical cognitive decline.

Theoretical Implications

The present results provide further evidence that PEs have diverse cognitive underpinnings beyond learning, which is also evident in prior research on alternate forms showing residual PEs despite changes in test content (Beglinger, Gaydos, et al., 2005; Benedict, 2005; Benedict & Zgaljardic, 1998). These residual PEs could be attributable to implicit memory processes, but may also result from other cognitive phenomena, including novelty effects (Benedict & Zgaljardic, 1998). Further, the cognitive processes that contribute to PEs may explain different patterns of PEs associated with particular clinical populations. The present study offers the first attempt to investigate this empirically and adds to our understanding of PEs by demonstrating unique contributions of memory and novelty effects to PEs across a spectrum of cognitive decline. Importantly, novelty effect has been shown to be unrelated to explicit memory, both in this study and in our prior research (Suchy et al., 2011).

The novelty effect appears to be distinguishable from explicit memory, but we currently have a poor conceptual understanding of novelty. It is possible that the novelty effect merely reflects implicit learning, which is dissociable from explicit memory (Squire, 1994) and may be relatively preserved in MCI and early Alzheimer's disease (Akdemir, Cangöz, Örsel, & Selekler, 2007; Gobel et al., 2013). Alternatively, the novelty effect could reflect other cognitive processes, such as controlled attention or strategy selection. The cognitive and neuroanatomical correlates of novelty effects need further investigation to explicate their contribution to PE, to determine whether novelty effect is distinct from procedural learning, and to better understand the contexts in which PE and/or novelty effect may have the best clinical utility. Although these cognitive and neuroanatomical correlates have not been examined directly, several lines of research offer insights into the possible correlates of novelty effects.

Possible cognitive correlates of novelty effects. Novelty effects may reflect specific aspects of executive functioning, such as controlled attention, which are involved in set formation or shifting. For example, learning curves research has shown a ubiquitous exponential performance pattern marked by large improvements within the first few trials of a task (Heathcote, Brown, & Mewhort, 2000; Newell & Rosenbloom, 1981), often referred to as a fast-learning stage, which is akin to our definition of novelty effect. This initial leaning stage is thought to be related to attention, response selection, and development of novel associations between stimuli and responses (Halsband & Lange, 2006). In addition, temporary performance decrements (i.e., slower response times and/or increased errors) are consistently observed in task-switching paradigms (e.g., Biederman, 1972; Rogers & Monsell, 1995) or in response to the reorganization of previously rehearsed task items (Ouellet, Beauchamp, Owen, & Doyon, 2004). Novelty effects may also be associated with fluid intelligence. For example, lower fluid intelligence has been associated with larger PE (Blalock & McCabe, 2011), perhaps due to a novelty effect. That is, individuals with lower fluid intelligence demonstrated lower initial performance on a working memory task relative to those with high fluid intelligence (presumably due to taking longer to extract the most relevant demands of a given task and therefore taking longer to engage the relevant cognitive processes), but had a relatively equivalent performance after practice with the tasks.

Suchy et al. (2011) proposed that novelty effect may be a marker of declining cognitive reserve, a cognitive “buffer” that protects against behavioral manifestations of neurodegenerative disease. Cognitive reserve may mask cognitive decline through greater activation or broader recruitment of brain regions to support performance of novel tasks (Eyler, Sherzai, Kaup, & Jeste, 2011; Lenzi et al., 2011). However, activation of broader networks likely comes at a cost early on in task performance; this cost may take the form of longer response latencies while networks are being activated, reflecting the response to task novelty. Thus, individuals with lower cognitive reserve may exhibit larger novelty effects.

Possible neuroanatomical correlates of novelty effects. A common network of regions emerges across neuroimaging studies of novelty processing, including prefrontal (Barceló, Periáñez, & Knight, 2002; Fabiani & Friedman, 1995) and cingulate cortices (Berns, Cohen, & Mintun, 1997; Knight & Nakada, 1998). However, these regions are also implicated in learning, specifically during the initial fast-learning period. For example, in their review of practice-related changes in brain activation, Kelly and Garavan (2005) described greater activation of prefrontal, posterior parietal, and anterior cingulate cortices early on during practice that decreases as performance becomes more automatic. They interpret this pattern within a "scaffolding-storage framework" (Petersen, Van Mier, Fiez, & Raichle, 1998) of practice in which frontal regions provide scaffolding during effortful performance to support adaptation to novel task demands, after which a different set of regions supports storage of associations or abilities needed for skilled performance. This scaffolding-storage framework offers an interesting parallel to the contributions of novelty effects and learning to PEs.

Clinical Implications

Early detection of cognitive decline is becoming increasingly important as new pharmacologic and behavioral interventions are developed for treatment and prevention of cognitive decline. The present results build upon prior evidence for the clinical utility of PE (Duff, 2012; Duff et al., 2007; Duff, Callister, et al., 2012; Duff, Chelune, et al., 2012; Machulda et al., 2013) and novelty effect (Suchy et al., 2011) in detection of cognitive decline. First, they indicate that PEs may reflect different cognitive constructs depending on the test used to measure PEs. For example, tasks with a significant learning component appear more likely to yield smaller PEs with cognitive decline (Schrijnemaekers et al., 2006). In contrast, tasks that require adaptation to novel procedures and/or those with less reliance on explicit learning or memory may yield larger PE (Yan & Dick, 2006) during early stages of decline. Additionally, it must be considered that like PEs, not all cognitive domains are equally impacted by cognitive decline nor do they decline at the same rate. For example, a large-scale longitudinal study of PEs and cognitive decline in older adults demonstrated different patterns of PE and cognitive changes across cognitive domains as well as between participants who did and did not go on to develop MCI or dementia (Machulda et al., 2013). Identifying measures that are most sensitive to cognitive decline in a specific cognitive domain may yield new methods for differential diagnosis. For example, PEs on an explicit memory test may be much smaller for a patient with early Alzheimer's disease due to impaired memory processes (Schrijnemaekers et al., 2006) whereas PEs may be larger for a patient with frontotemporal dementia because memory is relatively preserved (Glosser, Gallo, Clark, & Grossman, 2002; Wicklund, Johnson, Rademaker, Weitner, & Weintraub, 2006).

Second, variations in the relationship between PEs and cognitive decline across cognitive measures could have implications for interpretation of serial assessments. For example, a large PE on some measures may be indicative of intact or improving cognitive functioning, but a large PE on other measures may represent impairment or early signs of an incipient neurodegenerative disorder. Reliable change indices (RCIs) have been developed to address practice-related variance in repeat test performance (Chelune & Franklin, 2003; Duff, 2012); however, RCIs are typically calculated using test-retest data from healthy samples, which may not accurately reflect retest variability in impaired populations.

Finally, although PEs and novelty effects appear to have promise as a means to detect preclinical cognitive decline, further investigation into methods for measurement of novelty effects is needed. For example, Dutilh et al. (2009) noted that gross performance measures (e.g., total completion time or total accuracy) may wash out important variables related to PE and its subcomponents, such as novelty effects. They proposed that the use of diffusion models (e.g., Ratcliff & McKoon, 2008), which allow for a finer analysis of item-level data that contribute to overall task performance, will enable a more thorough examination of PE and their component cognitive processes, such as the novelty effect. Computerized tests of motor skill acquisition, such as the PTT task used in this study and previous work by Suchy et al. (in press) and Suchy et al. (2011), seem to be particularly well-suited to the task as they provide multiple measures of motor performance, such as planning time and response time, and allow for distinctions between accurate and inaccurate trials. Similarly, scale of analysis is also important when examining changes in novelty effects with cognitive decline. For example, increases in the novelty effect may occur only within a relatively narrow window of preclinical decline, and as such may be subsumed into linear models, especially when the range of functioning is broad with only a small number of participants representing the curvilinear inflection point. Further, alternative methods for measurement of novelty processing may prove useful diagnostically. For example, several studies suggest the utility of personality assessment for detecting incipient cognitive decline (Low, Harrison, & Lackersteen, 2013), with the Openness to Experience factor on the NEO Personality Inventory showing particular promise (Williams, Suchy, & Kraybill, 2013). It may be the case that behavioral changes assessed by Openness to Experience reflect subtle declines in novelty processing that are difficult to detect with traditional cognitive tests.

Limitations

The current study has several limitations. First, and most importantly, our ability to detect a mediating effect of learning on the relationship between cognitive status and PEs was limited by high correlations between measures of learning and cognitive status, leading to overlapping variance in the prediction of PE_{Coding}. Such high correlations may be in part due to the fact that DRS-2 scores are heavily weighted on memory performance and thus correlate highly with memory tests (Smith, Ivnik, Malec, & Kokmen, 1994). Future research should examine these relationships using other indices of cognitive decline, as well as populations whose cognitive decline is not characterized primarily by memory changes. It remains to be seen whether different patterns of cognitive decline will have a differential impact on PEs; however, preliminary support for this idea is evident in studies demonstrating that PEs vary across clinical diagnoses (Duff et al., 2007), suggesting that they are likely to vary in course as well, with some clinical groups demonstrating linear relationships between PEs and decline and others demonstrating curvilinear patterns.

Second, cognitive decline was not measured directly, but was estimated using scaled scores adjusted for age and education. Whereas scaled scores provide a reasonable estimate of a deviation from expectation, which in turn can be interpreted as reflecting cognitive decline, it is also possible that low-scaled scores may represent longstanding below-average cognitive functioning for some participants. Therefore, a direct measure of change in cognitive status is needed for a more accurate analysis of patterns of PE and the relative contributions of associated cognitive processes along a spectrum of cognitive decline. Use of a longitudinal or prospective cohort design would address this issue and may also allow for examination of the utility of PEs and proposed component processes for detecting risk for decline. Further, it should be noted that decline may be either global or limited to specific cognitive domains. Thus, examination of the relationship of domain-specific decline and PEs may yield additional insights that cannot be gleaned from the present study.

Finally, another limitation concerns generalizability with respect to retest intervals. The present study used very brief (30-minute) within-session practice intervals, as these have shown promise for diagnostic use (Duff, Chelune, et al., 2012). Practice intervals used in the current literature range widely from hours (within-session) up to years. These varying intervals are apt to yield substantial differences in the degree to which specific cognitive processes relate to PEs. Future research should focus on identifying the optimal practice interval at which PEs are useful for detection of decline. For example, novelty effects may have a stronger influence on PEs within a testing session because it reflects rapid improvement that may occur within a few trials of a test and is likely to return after delays or interruptions in task performance (Allport & Wylie, 2000; Raichle, Fiez, Videen, & MacLeod, 1994). In contrast, memory processes may contribute to PEs across longer retest intervals because improvements due to learning are more lasting.

Conclusions

To our knowledge, the present study provides the first examination of the unique contributions of novelty effects and learning to PEs across a continuum of cognitive status. The results support the unique effects of explicit learning and novelty effects on two different measures of PEs and suggest that these contributing variables may differentially influence PEs at various levels of overall cognitive functioning. The results provide preliminary insights into cognitive processes that underlie PE, but further research is needed if PEs are to be used as a diagnostic indicator.

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